Site-selective magnetization measurements using nuclear resonant scattering

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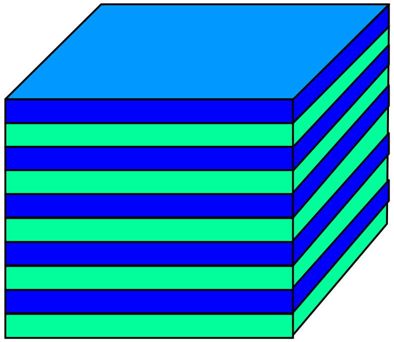
I. Introduction

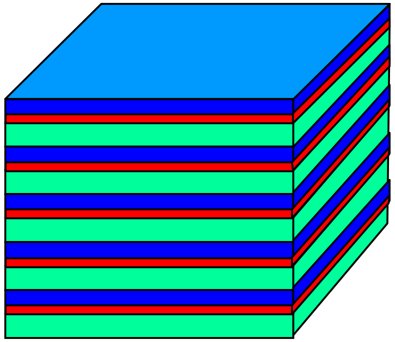
Site-selective magnetization measurements :

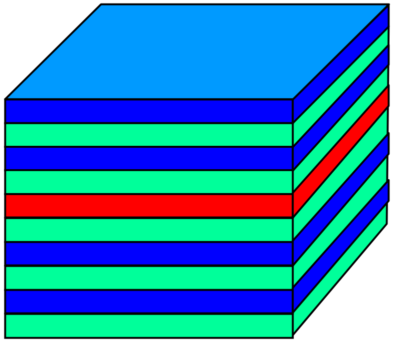
- XMCD



- element-specific scattering
- study different materials independently

- Nuclear resonant scattering





- isotope-selective scattering
- study specific sites within
  the material seperately

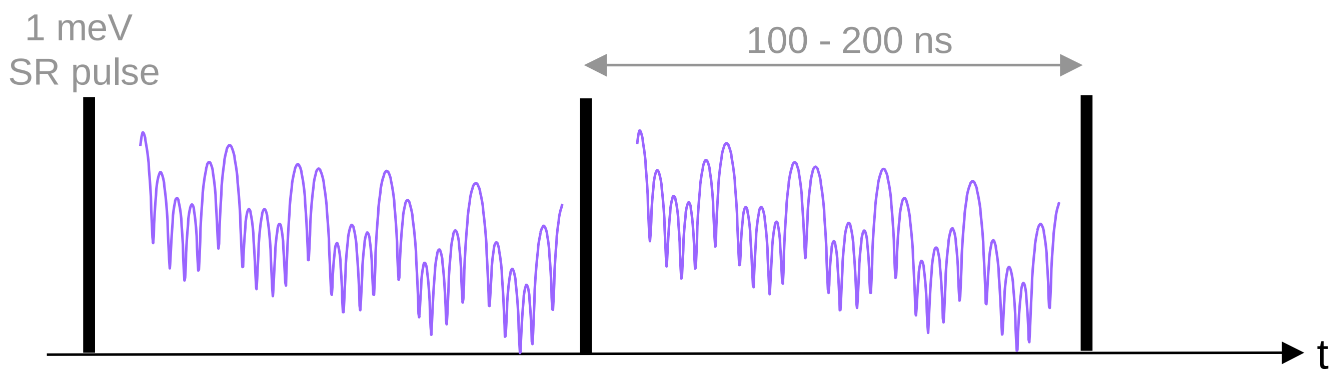
II. Nuclear resonant scattering

Nuclear resonant scattering of synchrotron radiation :

- isotope-selective technique : only scattering on the resonant nuclei (^{57}Fe)
- measures the local hyperfine interaction in the sample

- isomer shift	~ chemical environment of probe nuclei
- electric field gradient	~ lattice symmetry around the probe nuclei
- magnetic hyperfine field	~ magnetization properties

- measures the resonantly scattered synchrotron radiation versus time

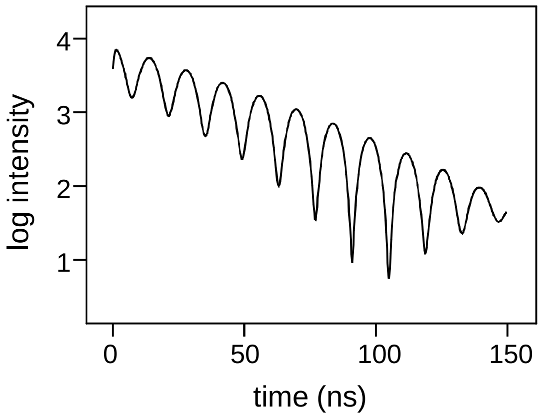


Information in time spectra

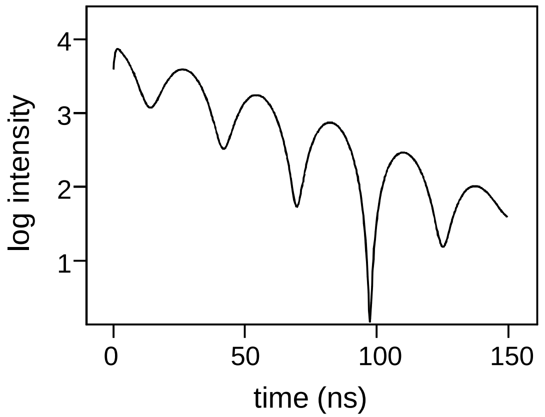
The time spectrum is

- sensitive to the <u>magnitude</u> of the magnetization vector

M = 1.76 J/Tm^3



M = 0.88 J/Tm^3

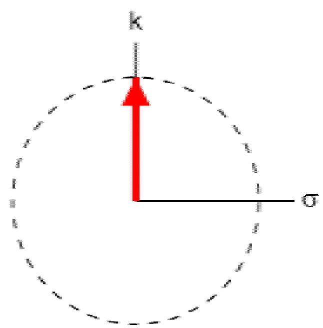


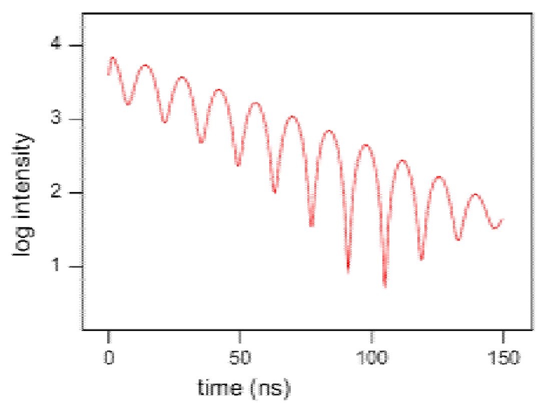
⇨ beat frequency ~ magnitude of M

Information in time spectra

The time spectrum is

- sensitive to the <u>magnitude</u> of the magnetization vector
- sensitive to the <u>direction</u> of the magnetization vector

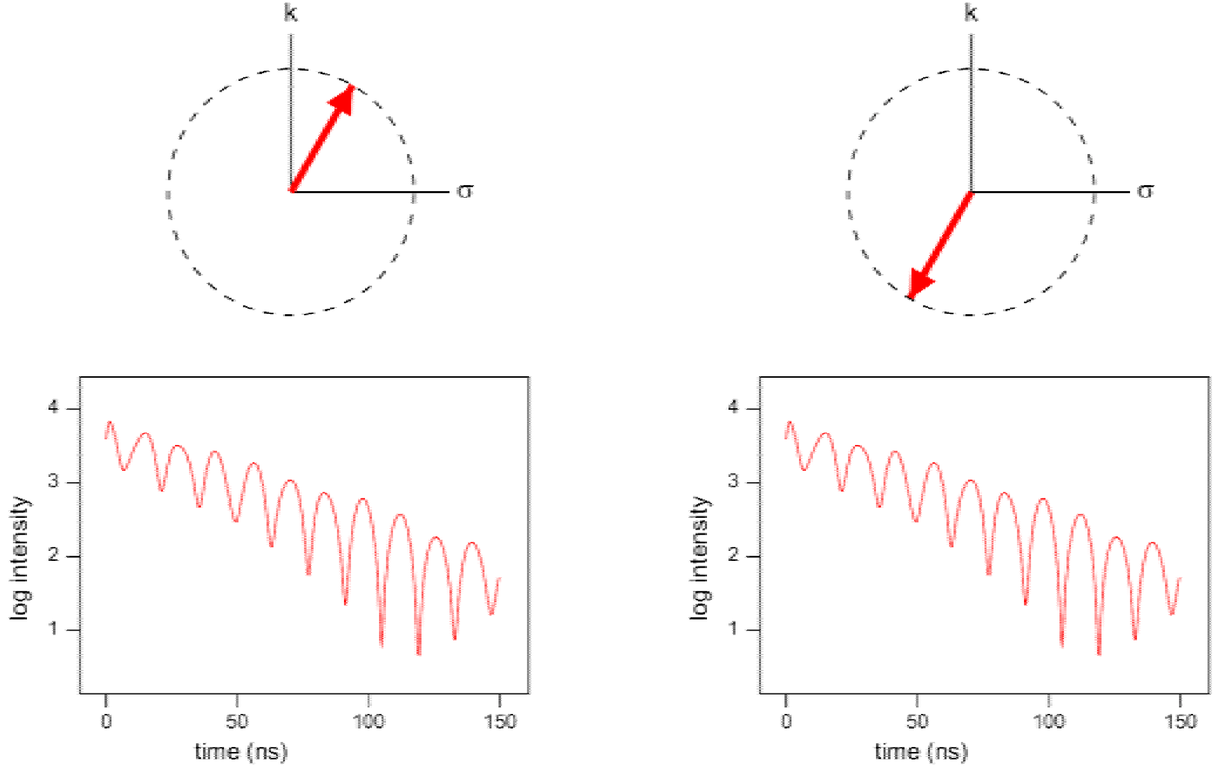




Information in time spectra

The time spectrum is

- sensitive to the <u>magnitude</u> of the magnetization vector
- sensitive to the <u>direction</u> of the magnetization vector
- restriction :



⇨ two opposite directions of M give exactly the same time spectrum !

Information in time spectra

The time spectrum is

- sensitive to the magnitude of the magnetization vector
- sensitive to the direction of the magnetization vector
- restriction : NOT sensitive to the sign of the magnetization vector

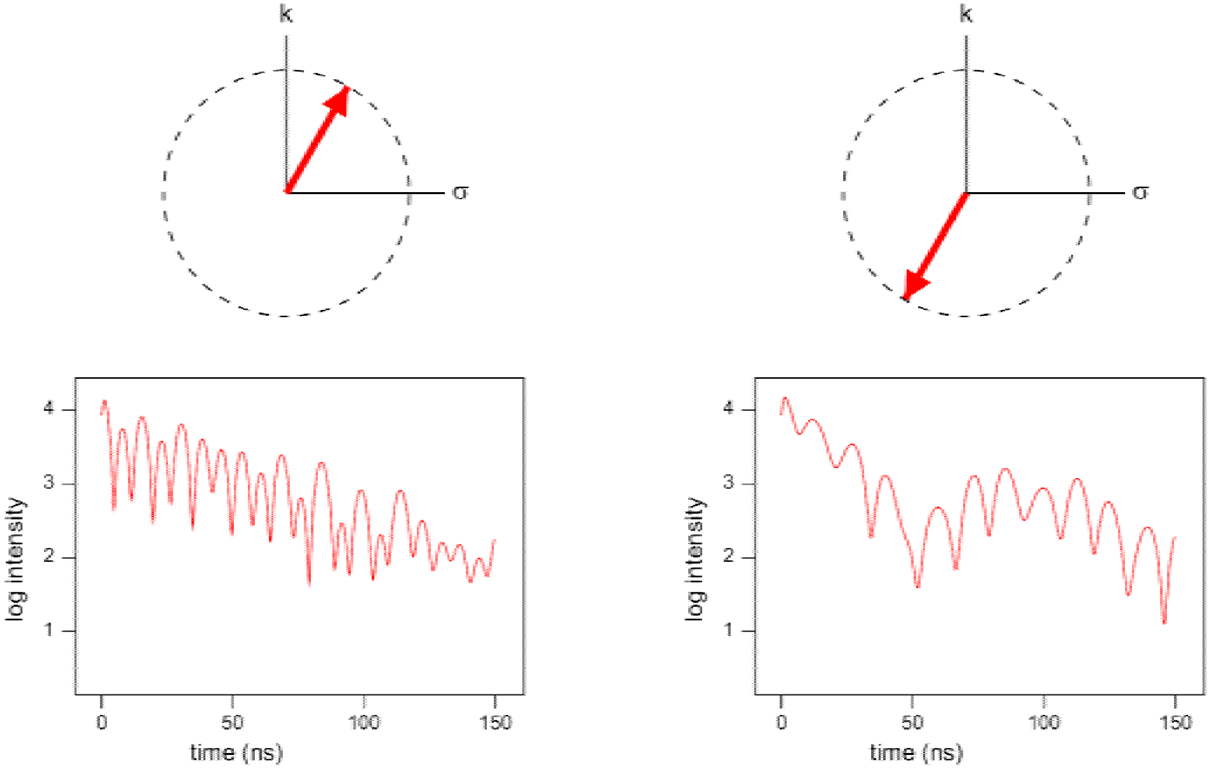
Explanation :

because the incident radiation is linearly polarized

the scattering process is not sensitive to the sign of M

III. Circularly polarized radiation

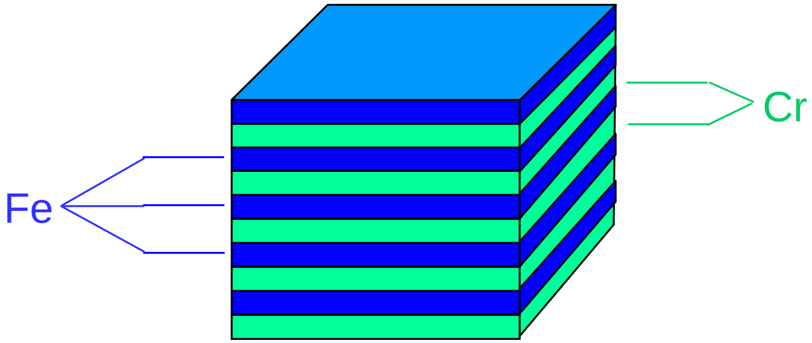
In order to measure also the sign of M one has to use circularly polarized radiation



⇨ two opposite directions of M give clearly distinct time spectra !

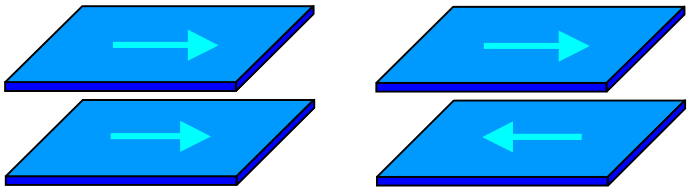
IV. Interlayer coupling in Fe/Cr multilayers

Fe/Cr multilayers :

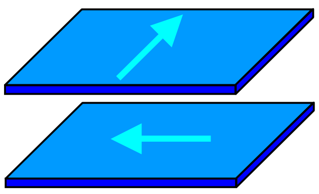


Depending on the Cr layer thickness, the Fe magnetization vectors will align :

- under 0° or 180° : bilinear coupling

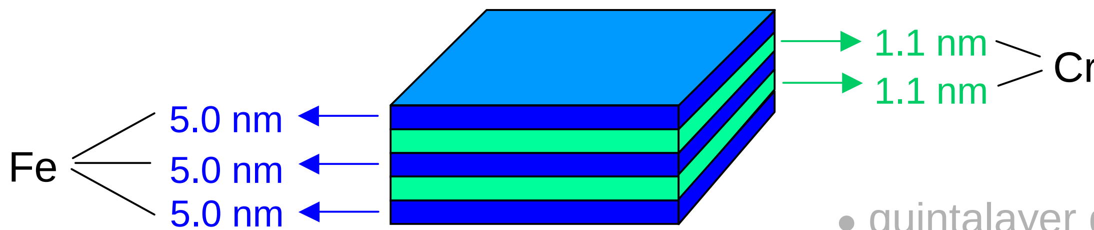


- under 90° : biquadratic coupling



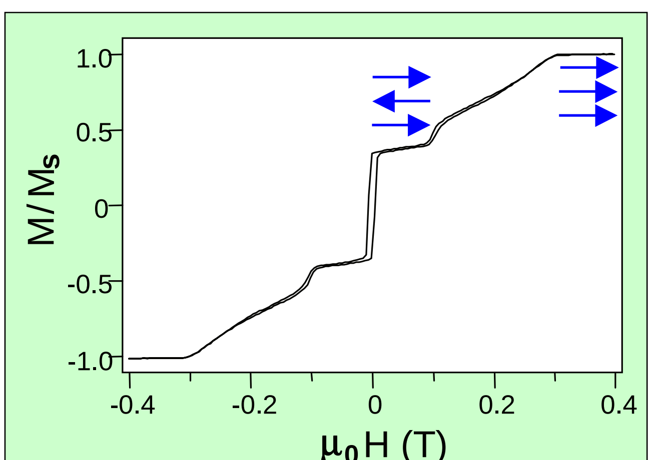
In order to study the interlayer coupling in detail :

- simplify the multilayer system :



- quintalayer grown on MgO(100)

standard magnetization measurement :



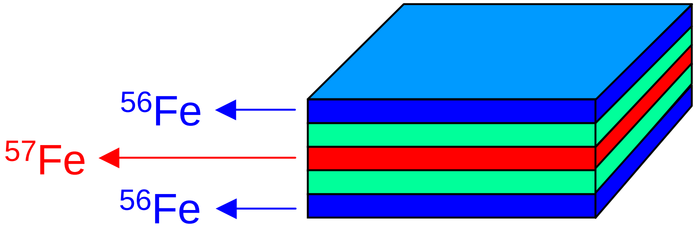
⇨ measures the response of all Fe layers together

How can one measure a magnetization curve of 1 layer selectively ?

In order to study the interlayer coupling in detail :

- simplify the multilayer system :
- measure magnetization of each Fe layer independently

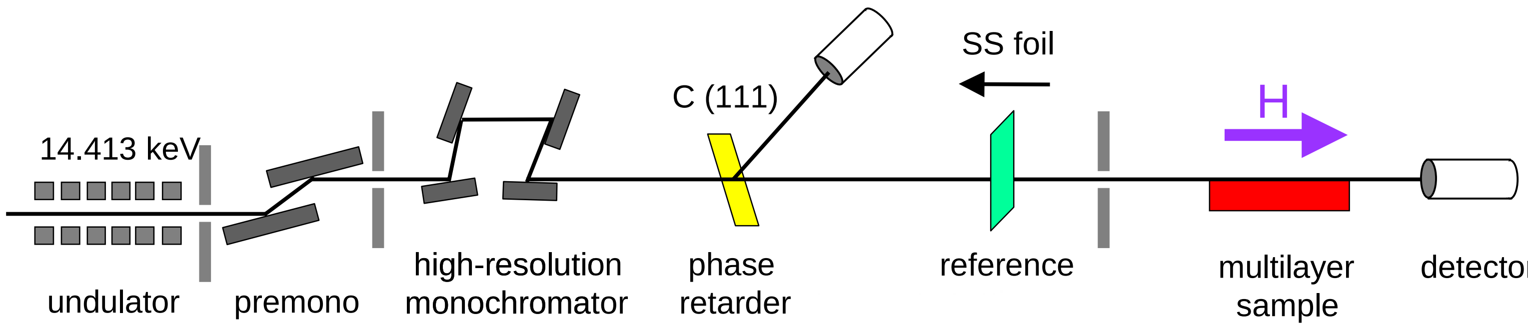
Use the isotope-selectivity of nuclear resonant scattering :

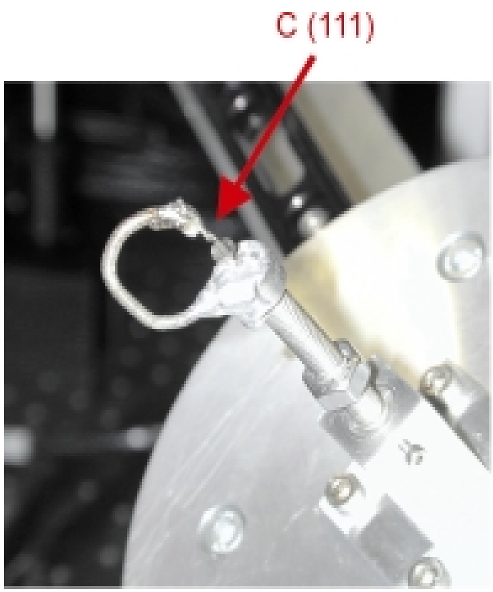


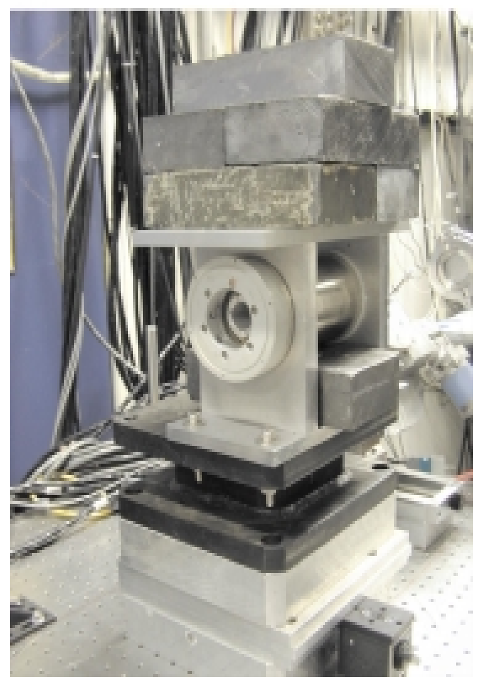
- buried ^{57}Fe layer
- quintalayer grown on thick MgO(100)

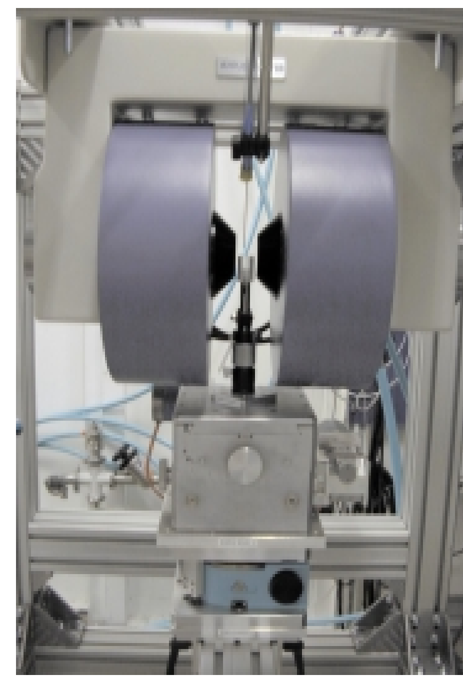
Measurement yields the magnetization vector of the central Fe layer

Experiment at APS beamline 3-ID

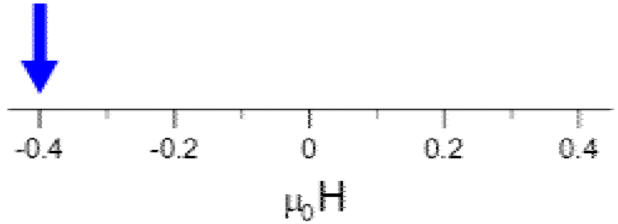


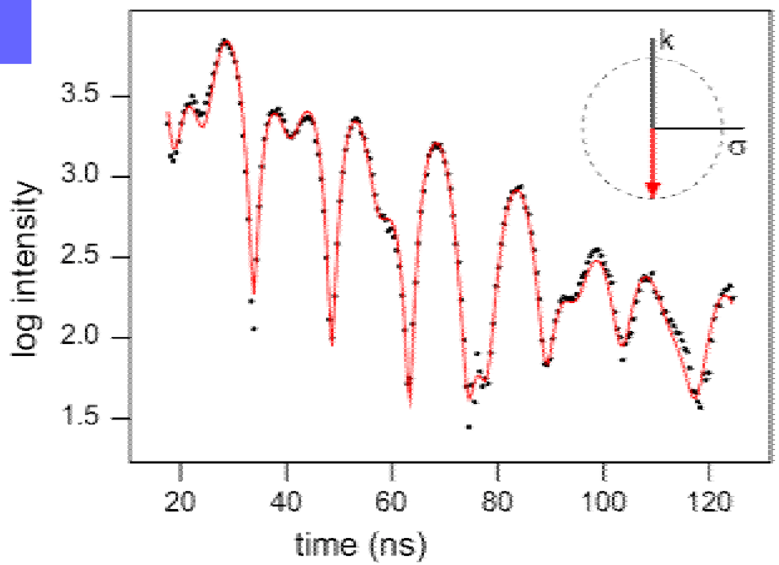




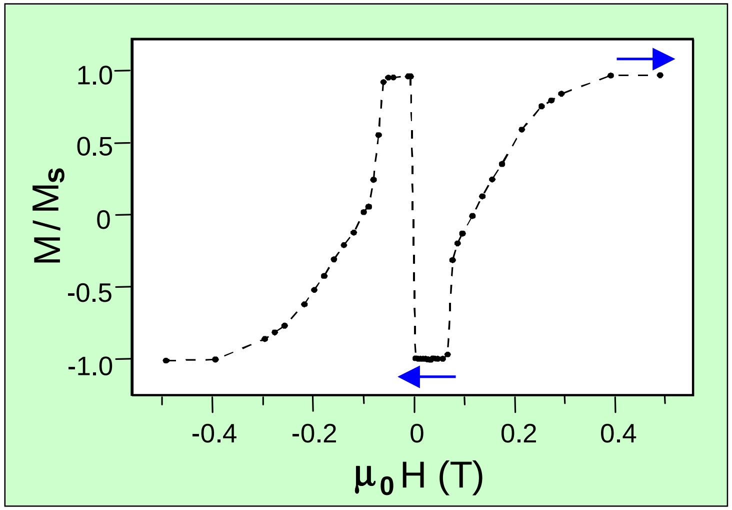


- Sample grown with MBE on MgO(100) :





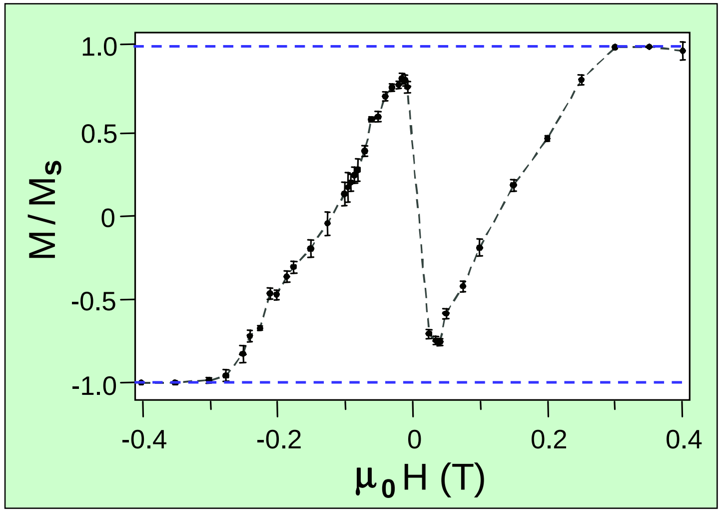
Nuclear resonant magnetometry



⇨ isotope-selective magnetization curve

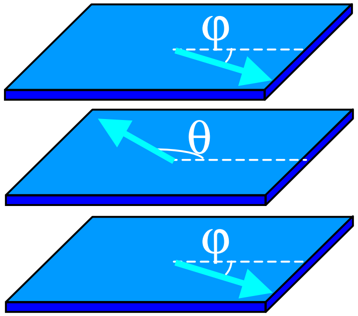
⇨ reflects only the central Fe layer

- Sample grown with <u>sputtering</u> on MgO(100) :



⇨ at zero field, the central magnetization vector is NOT antiparallel !!

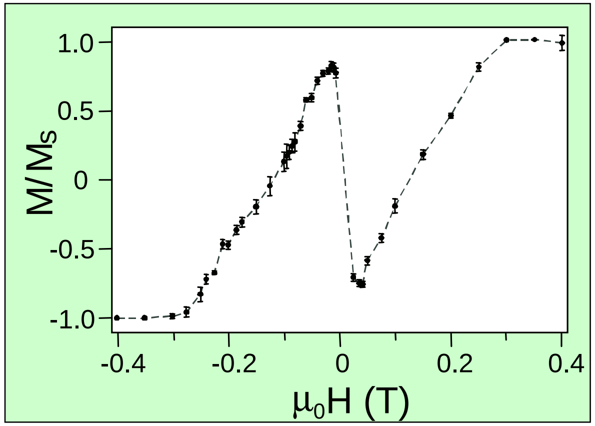
Retrieve quantitative values for coupling angle :



φ : angle of outer magnetizaton vectors

θ : angle of central magnetization vector

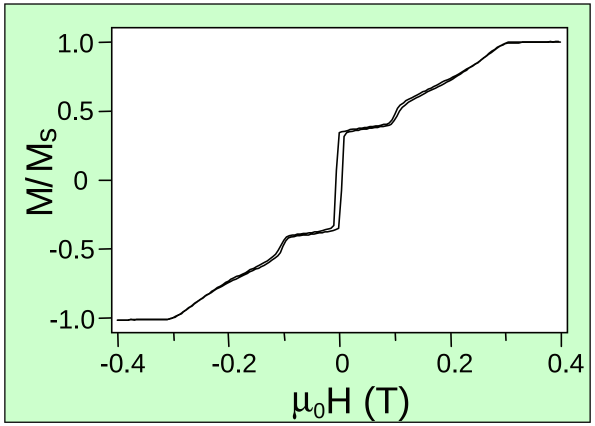
nuclear resonant magnetometry :



central Fe layer

$M/M_S = \cos\theta$

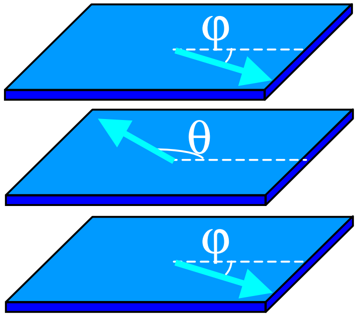
standard magnetometry :



all Fe layers

$M/M_S = (2\cos\varphi + \cos\theta)/3$

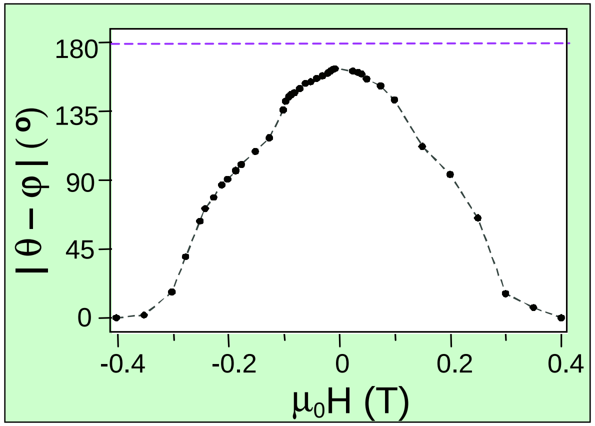
Retrieve quantitative values for coupling angle :



φ : angle of outer magnetizaton vectors

θ : angle of central magnetization vector

Combining the nuclear resonant magnetization data and the standard magnetization data detailed information on the interlayer coupling can be obtained



at zero field : $| \theta - \varphi | = 162° \pm 4°$

⇨ non-collinear coupling !!

V. Conclusions

- Nuclear resonant scattering with circularly polarized radiation permits to retrieve detailed magnetic information

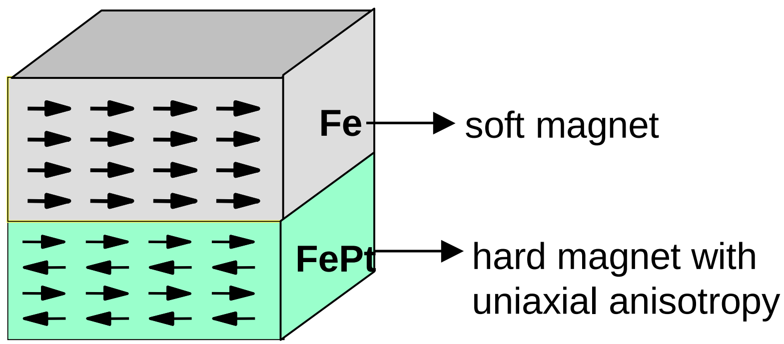
- We measured a layer-selective magnetization curve in $[Fe(5.0nm)/Cr(1.1nm)]_3$ and found

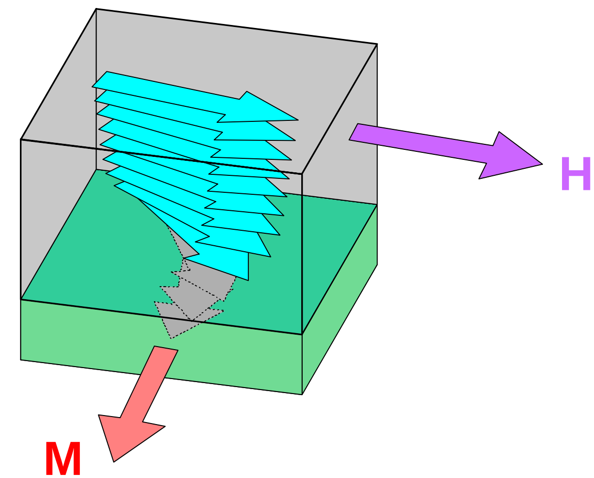
  - bilinear coupling for MBE-grown samples
  - non-collinear coupling for sputtered samples

C. L'abbé et al., Phys. Rev. Lett. 93 (2004) 037201

Perspectives : other applications

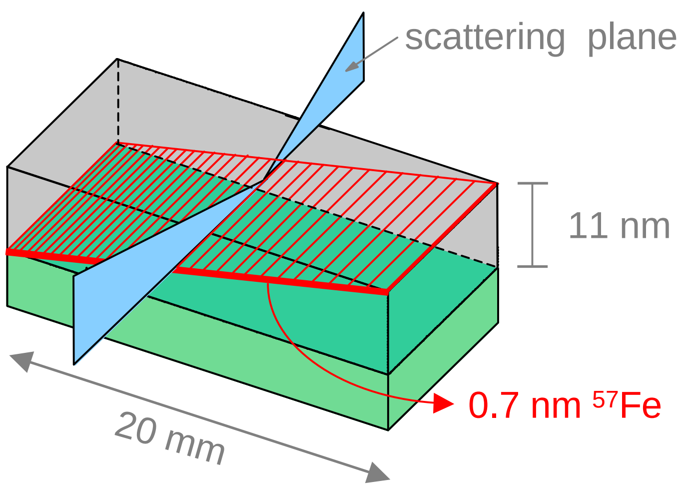
- depth-selective measurement of spinrotation in exchange-coupled bilayers :

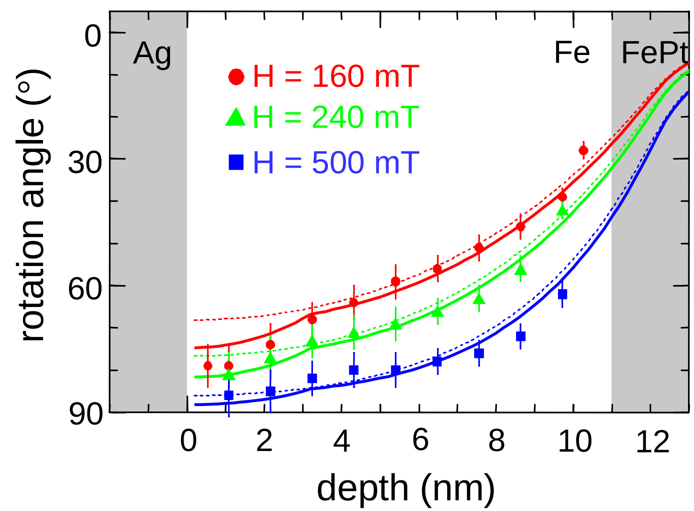




⇨ alignment of ferromagnet
by antiferromagent

⇨ exchange spring

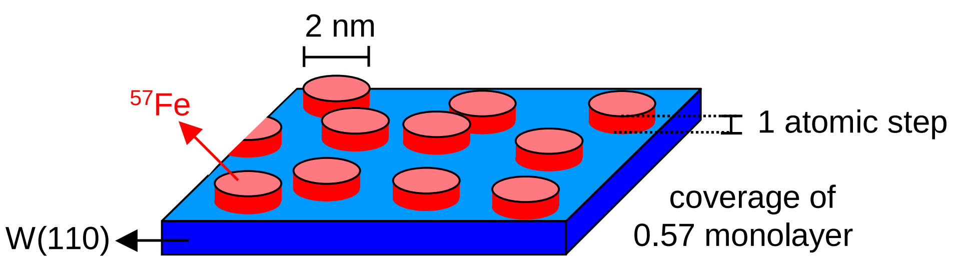


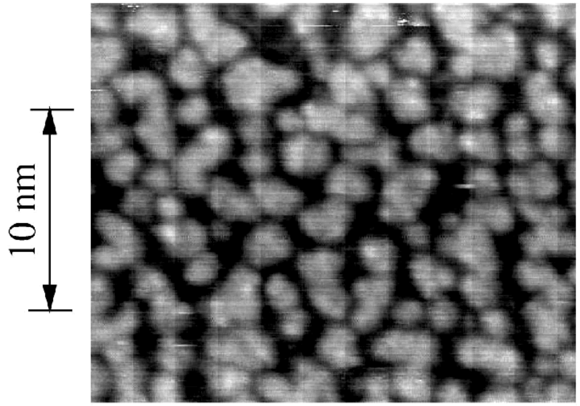


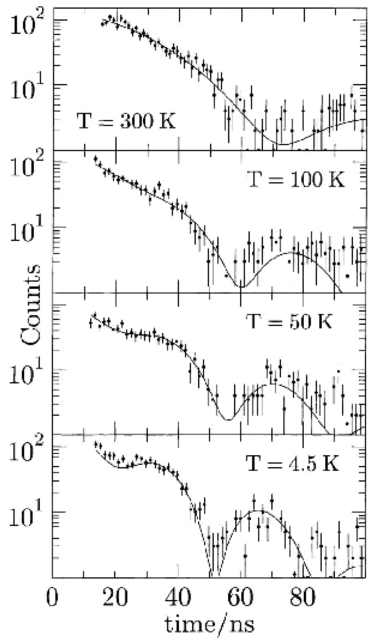
R. Röhlsberger et al., Phys. Rev. Lett. 89 (2002) 237201

Perspectives : other applications

- depth-selective measurement of spinrotation in exchange-coupled bilayers :
- measurement of nanoscale islands :







⇨ perpendicular spin orientation
in Fe islands below 100 K

R. Röhlsberger et al., Phys. Rev. Lett. 86 (2001) 5597

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